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OCEANOGRAPHIC CONDITIONS AND THE BLACK TUNA FISHERY
A translation

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Explanatory Note

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United States Department of the Interior, Oscar L. Chapman, Secretary
Fish and Wildlife Service, Albert M. Day, Director

ON THE RELATION BETWEEN THE TUNA FISHERY AND OCEANOGRAPHIC CONDITIONS

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I. Observations Concerning the Fishing Situation

a. History

The "tuna" referred to in this paper is the black tuna, Thunnus orientalis (Temminck & Schlegel). The drift-net fisnery for this species began when the fish were taken mixed in with the catch of rakudazame / Isurus nasus / (called nezumizame at Tokyo, moka in the Sanriku area, katōzame in Hokkaidō, and nezumizame in the following paragraphs). It is in a flourishing condition at present at Kushiro, Urakawa, Muroran, and Akkeshi. The long-line fishery operates in the waters between Erimosaki and Shiriyasaki and at times near Shikotan Island. Trolling and harpooning are sometimes carried on in conjunction with these fisheries. Set-net fishing is chiefly carried on in Funkawan, where it has the longest history, but in recent years it has also been established at Etorofu Island. The fisheries of each region will be discussed below.

Drift-net Fishery

Kushiro (1)

In 1905 the Shiranuka Fishing Guild made a trial of long-line fishing for nezumizame and caught one tuna. In the same year one Taumi, basing his operations at Akkeshi-Tokotan, fished a Niigata-type drift net off Daikoku-jima and made good catches of tuna and nezumizame. In 1906 at Kushiro one Ikeda began fishing on June 20 and caught one large tuna. He was joined by a number of others until the boats fishing totaled 17. In the following year, 1907, there were 38 vessels fishing; these were all sampans, but in 1914 two powered vessels entered the fishery. Good results were obtained, and the following year, 1915, saw the establishment of the Kushiro Tuna Drift Net Guild. In 1920 this organization was expanded and became the Kushiro Powered Fishing Boat Guild. In 1925 this Guild became the owner and operator of a fish and vegetable market, and the number of vessels fishing reached 43, forming the basis of today's prosperity. Fishing was good the next year, 1926, and from 1927 on the number of vessels participating rose above 200 and the value of the catch exceeded a million yen.

Urakawa

The year 1905 saw the beginning of the drift-net fishery for nezumizame, and the number of tuna included in the catch reached quite a figure. The number of tuna taken was particularly high in 1925, and the following year specialized drift-net fishing for tuna began. After 1928 the number of vessels participating rose above 30 and the value of the catch exceeded 100,000 yen.

Muroran

Washizu was the earliest, fish being taken there in drift nets around 1905. Just as at Urakawa, nezumizame were the main object of the fishery.

Akkeshi

Four drift-net boats began fishing in 1931, and 13 entered the fishery in 1932.

Long-line Fishery

The beginnings of this fishery were the tests of shark and tuna long-line fishing conducted by this Station from 1910 to 1914 on the Kitami coast, in Funkawan, and between Ezashi and Kutō. On the Pacific coast in 1913 the Kushiro Branch Station ran some trials off Akkeshi. In 1925 the Muroran Branch Station supplied long lines to fishing boats for experimental fishing. In the same year one Matsuda of Hakodate City fished successfully in the waters near Ezan, and in 1926 Technician Yokoyama and Assistant Technician Katsugi of this Station established this fishery firmly by their experimental long-line fishing. The vessels are based mainly at Hakodate and occasionally put in at Urakawa and Kushiro. Some long-line boats also troll. In 1927 a boat from Wakayama fished successfully.

Boats from Ōita Prefecture also engage in harpoon fishing, and in 1933 there were 40 harpoon boats from Chiba Prefecture based at Urakawa, where they operated successfully.

Set Nets

The set nets of Funkawan are the oldest, large catches having been made there at Kayabe-gun over 30 years ago.(2) Tuna are also taken incidental to the catch of other species on the Japan Sea coast in the Suttsu, Yoichi, and Mashike areas.

On the west coast of Etorofu Island some tuna have been taken in the salmon set nets for many years, but because of the lack of adequate transportation facilities no attention was given to them. With the development of refrigerated boats these fish have become profitable, and since 1917 tuna set nets have been established. At first they were used only in Utasutsuwan, but after 1925 they also began fishing at Tannemoe, Naibowan, and on the east coast. They were depressed by the rise of the Kushiro tuna fishery and also the number of fish migrating into the grounds fell off until at present set nets are operated only on the Utasutsu grounds.

b. Fisning Seasons, Fishing Grounds, Size of Fish

Drift-net Fishery

The drift-net boats of Urakawa and Muroran make their first catches in the coastal waters of Hitaka in the middle or latter part of June, while the boats based at Kushiro begin their season off Erimosaki in the latter part of June. In both cases the fishing is done 10 to 30 miles off shore. In the middle of July the whole area from Hitaka to Kushiro enters its peak season. Some years in August the fishery retreats northward to the region of Etorofu I. The main season in the waters off Kushiro is from the middle of July to the latter part of October and the grounds are about 20 miles off shore (along the fringes of the third branch of the warm current) and about 50 miles off shore (on the edges of the second branch of the warm current).

Table 1 shows the first day of fishing, the peak of the season, and the date fishing ends at Kushiro. We look next at the seasons for the various sizes of fish. In table 2 we have followed Mr. Kinosuke Kimura in taking as the median period the 10-day period which corresponds to the statistical mathematical average and then taking twice the breadth to be the peak season. Further, the number of large, medium, and small fish taken in each 10-day period on a 10-year average is shown in figure 1. According to this graph, the 10-day period at which half of the catch of large tuna had been taken was earlier than the mean period, while for the medium and small fish they more or less coincided. In neither case is the distribution of the catch very unsymmetrical. Table 3 shows the median period of the fishing season for each size of fish.

As far as the sizes of tuna taken in Hokkaidō are concerned, those from Etorofu Island are the largest, some of them attaining weights of 330 to 650 pounds. The next largest are the fish taken in the set nets of Funkawan in the autumn, many of these weighing around 330 pounds. At Kushiro, as is clearly shown in tables 2 and 3 and in figure 1, large fish predominate at the beginning of the season, with the average weight commonly over 250 pounds. Thereafter medium and small tuna appear, and by the middle of August the number of small fish exceeds the number of large ones. In October with the strengthening of the cold currents the small tuna are gradually driven out and the average size of the fish increases. Table 4 shows the average weights of fish for each month.

Long-line Fishery

The first long-line catches are made in August, later than those of the drift-net fishery. The fishing grounds are chiefly in the area from off Erimosaki to off Shiriyasaki and farther out to sea than the drift-net fishing grounds. The waters east of Erimosaki provide no good fishing except in the autumn when the tuna are returning southward. Good fishing is sometimes found to the southeast of Shikotan Island. The peak season is from September to November, and the last catches are made off Shiriyasaki in December.

Table 1.--Ready-reference table of Kushiro drift-net fishing seasons

Year	First catch		Peak period			Final catch		Notes
	Date	Ground	Month	10 days	Days	Date	Ground	
1918	6-13	off Kushiro	--	--	--	11-4	off Kushiro	Peak season Aug-Sept
1919	6-24	"	Aug	--	--	10-22	"	Main grounds about 20 mi. S/E of Kushiro
1920	7-5	"	Aug	--	--	10-19	"	
1921	6-25	"	Aug	--	--	--	"	
1922	7-2	"	July	July III	7-27	10-17	"	
1923	7-5	"	Aug	Aug II	8-11	10-20	"	
1924	7-1	"	Aug	Aug I	8-3	10-26	"	First fishing 6-26
1925	7-7	"	Aug	Aug III	8-14	10-31	"	
1926	7-11	30 mi. SW of Erimosaki	Aug	Aug I	9-12	10-27	off Erimosaki	
1927	6-20	60 mi. SW of Erimosaki	Aug	Aug III	8-27	11-2	8 mi. SSW of Erimosaki	First fishing 6-19, first catch in 11°C water off Shiriyasaki. First catch off Erimosaki 7-2, off Kushiro 7-7.
1928	6-27	35 mi. SW of Erimosaki	Sept	Sept III	9-22	11-24	off Erimosaki	First fishing 6-25, first catch in 16°C water.
1929	6-27	30 mi. SW of Erimosaki	Sept	Sept I	8-5	12-1	off Kushiro	First fishing 6-27, first catch in 14.5°C water.
1930	6-22	40 mi. SW of Erimosaki	Aug	Aug III	8-29	11-25	20 mi. SE of Kushiro	First fishing 6-22.
1931	6-30	off Erimosaki	Aug	Aug III	8-27	11-17		
Average	6-27				8-21	11-4		
Median	6-28				8-20	10-31		

[Translator's note.--I, II, and III refer to the first, second, and third 10-day periods of the month.]

Table 2.--Ten-year averages of seasons by sizes of fish (Kushiro)

Category	Median 10-day period	Mean 10-day period	2(spread)	Notes
Tuna	beginning of Aug III	Aug III	July II - Oct III	Not separated into large, medium, and small. Calculated by weight. All based on 10-year average from 1922 to 1931.
Large tuna	Aug II	Aug III	July I - Oct I	Over 165 pounds, calculated from number of fish.
Medium tuna	beginning of Sept I	Sept I	Aug I - Oct II	83 to 165 pounds, calculated from number of fish.
Small tuna	beginning of Sept II	Sept I	Aug I - Oct I	Under 83 pounds, calculated from number of fish.

Table 3.--Mean 10-day period of the season by year and size of fish

Year / Size	1922	1923	1924	1925	1926	1927	1928	1929	1930	1931	1932
Large	7-III	8-II	8-II	8-III	8-III	8-II	9-I	8-III	8-II	8-III	8-II
Medium	9-I	9-I		9-I	9-II	9-I	9-II	9-II	9-I	9-I	9-II
Small	9-I	9-I	9-II	9-II	9-I	9-I	9-III	9-I	9-II	9-II	9-I

[Translator's note.--The Roman numerals I, II, and III indicate the first, second, and third 10 days of the month.]

Table 4.--Average weight of tuna by months (Kushiro)

Month \ Year	1921	1922	1923	1924	1925	1926	1927	1928	1929	1930	1931
June	--	248.1	--	--	--	--	289.5	275.4	321.7	191.0	162.1
July	--	301.9	260.5	267.9	250.6	250.6	254.7	247.3	272.1	147.2	153.8
Aug	--	110.8	177.0	140.6	113.3	204.3	140.6	138.9	151.3	129.0	67.8
Sept	--	70.3	78.6	172.0	141.4	138.1	124.1	81.1	115.0	76.1	84.4
Oct	--	95.9	88.5	97.6	67.0	273.7	94.3	76.1	134.0	76.9	87.7
Nov	--	--	--	--	36.4	--	159.6	148.9	269.6	80.2	93.5
Dec	--	--	--	--	--	--	--	--	210.9	138.9	--
Average for whole period	87.7	160.4	164.6	156.3	112.5	177.8	146.4	110.0	153.0	105.0	81.1

Note.--The average for the whole period is not the average of the monthly averages.

[Translator's note.--Weights have been converted to pounds at the rate of 8.27 pounds per kan.]

Set-net Fishery

The set-net fishery in Funkawan is divided into the summer and autumn fisheries. The summer tuna are first taken in June, sometimes earlier than the drift-net fishery in Hitaka waters. At first large fish are taken, and small fish later. The peak of the summer season is in July. The autumn tuna begin in October and reach their peak in November. The first catches were made as follows: 1928, Mori June 17, Oshamanbe June 27; 1929, Mori June 29, Oshamanbe July 12; 1930, Mori July 1, Oshamanbe July 11; 1931, Oshamanbe July 10.

Amount of Catch

Table 5 shows the catch at Kushiro. In order to indicate clearly the quality of the fishing in each year, the average catch per cruise per boat is shown in table 6. Table 7 gives the catch of the Etorofu Island set nets.

c. Characteristics of the Fishery in the Past 10 Years

1922.--Kushiro had a poor year. In July there was good fishing for large tuna, but in August and September the fishing became poor. In September there was good fishing for small tuna of about 25 pounds weight on the coast. The appearance of the greatest catch of large tuna in July is abnormal.

1923.--A poor year at Kushiro. Small tuna were scarce. The Etorofu Island set nets had a poor year.

1924.--Kushiro had a poor year. Large tuna were predominant. There were absolutely no medium fish of 83 to 125 pounds. The Etorofu Island set nets made better catches than they had in the previous year.

1925.--Kushiro had a good year. There were many small tuna and the average size of the fish was small. The set nets at Etorofu Island had good fishing.

1926.--The Kushiro drift nets had good fishing. There were few small fish and the average size was large. The schools were sparse east of Akkeshi. Long-line fishing was good near Ezan, Hitaka, and Iburi. In November the set nets in Funkawan had good fishing, and at the same time large schools came into the Tsugaru Strait. The Etorofu Island set nets had poor fishing.

1927.--The Kushiro drift nets fared poorly. The schools moved north to the Shikotan and Etorofu areas and the grounds were widely scattered. Medium and small tuna were rather abundant. The long-line grounds extended to the waters of Hitaka and Erimo, but the fishing was very poor. Quite a few fish were taken by trolling. In July the set nets of Funkawan had large catches. The Etorofu Island set nets had their best fishing in 10 years.

Table 5.--Tuna catch by years at Kushiro

Year	Number of boats	Amount of catch			Average catch per boat		Average catch per boat per cruise
		Fish	Weight	Value	Weight	Value	
			Pounds	Yen	Pounds	Yen	Pounds
1916	9	--	--	19,450	--	2,161	--
1917	11	--	--	59,720	--	5,429	--
1918	39	--	--	193,158	--	4,953	--
1919	72	--	--	323,158	--	4,488	--
1920	53	--	--	186,918	--	3,527	--
1921	61	32,597	2,844,053	227,085	46,626	3,723	--
1922	63	11,256	1,659,086	230,089	26,332	3,652	--
1923	43	7,435	1,223,853	174,650	28,465	4,062	992
1924	53	7,795	1,218,436	176,945	22,991	3,339	827
1925	43	24,411	2,743,200	333,111	63,795	7,747	1,456
1926	103	39,501	6,890,961	841,635	66,904	8,171	2,531
1927	272	58,769	8,601,759	796,225	31,625	2,927	1,604
1928	187	87,865	9,151,822	1,330,671	48,942	7,116	1,439
1929	258	164,208	24,792,236	1,637,974	96,097	6,349	2,299
1930	250	141,112	14,780,285	1,178,470	59,122	4,714	1,472
1931	266	182,099	14,867,798	1,087,184	55,897	4,087	1,307
1932	262	69,683	9,446,350	480,060	36,057	1,832	1,083

Note.--Figures prior to 1921 include broadbill swordfish.

[Translator's note.--Weights have been converted at the rate of 8.27 pounds per kan.]

Table 6.--Average catch per boat per trip for Kushiro tuna boats (by weight) [in pounds]

Year \ Month	June	July	Aug	Sept	Oct	Nov	Dec	Whole year
1922	* 248.1	1,328.2	?	639.3	712.1	--	--	?
1923	--	872.5	1,360.4	380.4	541.7	--	--	992.4
1924	--	895.6	999.0	649.2	630.2	--	--	826.2
1925	--	961.8	2,037.7	1,258.7	946.1	1,099.9	--	1,458.0
1926	--	3,025.2	2,716.7	2,753.9	1,684.6	--		2,531.5
1927	1,884.7	1,888.0	2,065.0	1,011.4	1,008.1	*9,551.9	--	1,604.4
1928	3,303.9	1,276.1	1,292.6	1,944.3	1,048.6	1,696.2	--	1,437.3
1929	3,858.0	5,048.0	2,519.9	2,202.3	1,480.3	1,329.0	*215.0	2,294.9
1930	3,910.1	2,059.2	1,703.6	1,604.4	817.1	573.1	--	1,473.7
1931	2,588.5	1,840.1	1,600.3	1,310.0	975.9	624.4	--	1,303.4
1932	428.4	2,460.3	977.5	904.8	464.0	255.5	--	1,083.4

Note.--* indicates just one cruise of one boat. Each month was not averaged, but the total catch for the whole year was divided by the total number of trips.

[Translator's note.--Weights converted to pounds at the rate of 8.27 pounds per kan.]

Table 7.--Catch of Etorofu Island set nets

Year	First day of fishing	Final day of fishing	Amount of catch				
			Tannamoe	Naibowan	Utasutsu	Total fish	Total weight
							Pounds
1923	8-1	10-28	--	--	1,188	1,118[sic]	294,743
1924	7-28	11-1	--	--	3,074	3,074	889,769
1925	7-20	10-31	325	2,307	2,025	4,657	1,154,409
1926	8-2	10-12	214	577	764	1,555	385,796
1927	8-8	10-21	1,250	874	4,906	7,030	1,744,143
1928	7-27	10-30	549	1,600	4,600	6,749	1,674,427
1929	7-16	10-29	22	1,105	1,576	2,703	670,614
1930	7-29	10-20	--	736	1,525	2,261	560,954
1931	8-9	10-31	--	344	806	1,150	285,315

[Translator's note.--Weights converted at the rate of 8.27 pounds per kan.]

1928.--Fishing on the Kushiro drift-net grounds was poor in July and August, but good in September. In normal years the peak of the season comes in August, but this year it was in September. The end of the season was delayed and the fishing grounds were near the coast. The schools extended to the Etorofu Island area. Small tuna were numerous and the average size of the fish was small. The long-line grounds, centered around Erimosaki and extending to the waters off Kushiro, afforded good fishing. In November the set nets in Funkawan had good fishing, and at the same time there were dense schools in the Tsugaru Strait. The set nets at Etorofu Island had good fishing.

1929.--The Kushiro drift-net grounds had their best fishing in the 10-year period. The grounds did not extend east of Akkeshi and were close in to the coast. There were few small tuna and the average size of the fish was large. Long-line fishing was good on the grounds west of Erimosaki. The catch of the set nets in Funkawan was small, and the set nets of Etorofu Island had rather poor fishing.

1930.--The Kushiro drift-net grounds extended over a wide area from Erimosaki to the waters off Otchishisaki, and the fishing was moderately good, with no concentrated grounds. There were many small tuna and the average size of the fish was small. The long-line grounds had extremely poor fishing. The set nets in Funkawan made good catches of small tuna in August. The Etorofu Island set nets had poor fishing.

1931.--The Kushiro drift-net grounds were not as close to shore as in the previous year and their northern end was at Shikotan Island. The large tuna were unusually large in size, there were few medium fish, and small fish were very numerous. The average size of fish was the smallest in the 10-year period. The long-line grounds were good off Erimosaki in August and off Shikotan Island in September and October. The set nets of Funkawan had good autumn fishing. The Etorofu Island set nets had poor fishing.

1932.--Big catches were made at Kushiro in the latter part of July, but from August on the fishing was very poor. Medium tuna were very scarce. Urakawa had the best fishing in years, and small tuna were remarkably abundant. The long-line fishing was poor.

II. Observations Concerning Habits

a. Migrations

In ascertaining the migrational movements of fishes there is the direct method of tagging and then recapturing the fish under consideration, and there is the indirect method of hypothesizing these movements from the shifts in the seasons and grounds. The latter is liable to be confused with changes in environmental conditions, but in the case of large tuna, which are difficult to tag, this deductive method must be used.

With regard to the tagging of tuna, Technician Yokoyama of this Station has devised the method of using a regular trolling line rigged so that when a fish strikes the tag, the hook and a part of the leader will break off.

Table 8 shows the results of the tagging of small tuna from the set nets of Yoichi and Furuhira in August and September 1933, by Assistant Technician Nakashima of this Station, using tags attached to the caudal peduncle.

From these facts it appears that although the fish make small localized migrations in search of food during the summer season, they move southward with the falling water temperatures in the autumn. It should be borne in mind, however, in this example that the fish were released at just about the northern limit of their area of migration.

Since taggings of small tuna are scheduled for the Pacific Coast in the future it is to be expected that migrations of this sort will gradually become clarified. However, in the present paper we will expound our hypothesis concerning the migrations of the tuna in the Pacific coastal waters of Hokkaidō based on observation of the shifts in the fishing seasons and the fishing grounds.

The place in Hokkaidō where the earliest catches of tuna are made is in the set nets of Kayabe-gun, following the northern part of Aomori Prefecture. Therefore these schools must be fish which have been drawn from the Iwate area by the Tsugaru Current and have moved north through the waters off Shiriyasaki. The theory is also held that they migrate from the Japan Sea through the Tsugaru Strait, but the truth or falsity of this waits upon future investigations. Next the Kushiro and Urakawa drift-net boats make their first catches in the latter part of June from 30 miles south of Erimosaki to off Hitaka. These schools, through the third branch of the warm current described in a later section, move north farther off shore than the previously mentioned fish. In some years these schools move on from the Kushiro area north to the Etorofu area. Part of them must turn left from the coastal waters of Hitaka to enter Funkawan. Furthermore, some of the fish off Kushiro move north along the second branch of the warm current. The above are the deduced migrations of the so-called ascending tuna, east of Erimosaki the large tuna migrating comparatively close to the coast while the small fish are farther off shore. From the latter part of September to October the fish gradually begin to move south. Their route follows the outer edge of the coastal stream of the Chishima cold current to the waters off Erimosaki, from where some of the fish head for the Funkawan and Shiriyasaki areas while others head for the Kamaishi area. There appear to be some fish which move southward off shore with the retreat of the second branch of the warm current off Kushiro. The above is what may be called the grand migration, however, along the route at Shiriyasaki, Erimosaki, and off Kushiro there are localized migrations covering considerable periods of time. These are food-seeking migrations which

Table 8.--Taggings and recoveries of small tuna (as of February 1, 1933)

Release			Recapture			Elapsed days	Distance	Average day's run	Notes
Place	Date	Gear	Place	Date	Gear				
							Miles		
Yoichi-saki Shiriba-saki	8-12-32	mackerel set net	Takashima-machi Shukutsushi-Yamanaka	9-4-32	mackerel	23	9	0.5	9 released 3 recaptured -- recapture rate 33%
"	"	"	Furuhira-machi Irifune-machi	10-11-32	salmon set net	60	6	0.1	
"	"	"	"	11-11-32	"	93	6	0.07	
"	8-23-32	"	"	---	---	--	--	--	2 released, no returns
Furuhira-machi Irifune-machi	9-28-32	salmon set net	Yoichi-machi Okimura	10-20-32	mackerel set net	22	5	0.2	39 released 3 recovered -- rate of re-capture 7.7%
"	"	"	Furuhira-machi Irifune-machi	10-7-32	salmon set net	9	0	0	
"	"	"	Morohashi-mura, Hoshi-gun, Ishi-kawa-ken	12-10-32	yellow-tail trap net	73	439	6.0	

unquestionably change with the changes in the movements of sardines and squid dependent on the changes in oceanographic conditions. The increasing size of the fish as one goes farther north means that one must take into consideration the fact that the larger tuna are, as set forth in a later section, more adaptable to water temperatures than the medium and small fish, together with the fact that the larger the fish the greater is its speed of migration.

b. Favorable Temperatures

Time of first catch and water temperatures

If we present the surface water temperatures measured by survey vessels at the time of the first catches, we find that on July 2, 1926, 30 to 50 miles south of Erimosaki, when a school of large tuna was sighted, it was 12.2°C to 13.6°C, and on July 11, 1927, 20 miles south of Urakawa the Sanyō Maru, which had sighted a school of large tuna, found a temperature of 13.5°C. Similar records taken by fishing vessels are 11.0°C for the place where the first catch was made on June 20, 1927, 60 miles southwest of Erimosaki (off Shiriyasaki), 16.0°C where the first catch was made on June 27, 1928, 35 miles southwest of Erimosaki, and 14.5°C where the first catch was made on June 27, 1929, 30 miles southwest of Erimosaki. Thus the water temperatures on the grounds where the first catches are made, which in normal years are about 30 miles south of Erimosaki, are about 14°C. The first catches are made at higher temperatures in warmer years and at lower ones in colder years, but a zone of water of over 12°C should be sought.

Peak season and water temperatures

There have been few years in which the fishing grounds off Kushiro have shown water temperatures higher than 20.0°C, and the lowest recorded is about 13.0°C, like the temperatures of 1926. Generally the range is 14.0°C to 18.0°C. Ten miles south of Hitokappu on Etorofu Island on August 24, 1927, the Sanyō Maru sighted a large school of tuna in water of 9.9°C, and on September 24 of the same year 40 miles south of Hitokappu a large school of tuna was sighted in water of 12.5°C. Since 1927 was a warm year, in normal years the fish must move northward in the Chishima area through zones of water of 10.0°C or colder.

End of the season and water temperatures

Although there are no observations of water temperatures at the end of the season, there must be times when good fishing is found at temperatures of around 10.0°C.

At the time when they are moving northward through Hokkaidō waters the tuna schools are seen in the waters of the warm-current system. However, they gradually become accustomed to cold water and many of them pursue schools of sardines even into zones of low-temperature, turbid water (water color below 6, transparency less than 5 meters), so it is difficult to infer the area of migration from water temperature. Furthermore, because the water temperatures at which the fish occur vary from year to year and from area to area, it is hard to determine accurately what is the most favorable temperature. In the foregoing only the surface temperature has been considered. It is, nevertheless, an error to think that the vertical movements of the tuna take place only between the surface and a depth of 20 meters, for in the waters east of Erimosaki they go far deeper, down to 100 meters, as is presumed from the fact that they are hooked on octopus long lines. Even in the waters east of Erimosaki, where the temperatures at the deeper levels are low, the fish must descend to depths greater than 40 meters judging by the length of the long-line branches. There must be cases in which the water temperatures are 5.0°C or lower, and from this it can be seen that the adaptability of the tuna to temperature is surprisingly great. Figure 2 shows the average surface temperature and the catch by 10-day periods along a line 10 to 50 miles south from Kushiro.

c. Inhabiting Zones of Mixed Water

Tuna are abundant in areas where different water masses are mixed.
Examples: Near Shiriyasaki, Tsugaru warm current ≠ coastal stream of cold current
Near Erimosaki, third branch of the warm current ≠ Tsugaru warm current ≠ coastal stream of cold current
Coastal grounds off Kushiro, third branch of warm current ≠ coastal stream of cold current
Kushiro off-shore grounds, second branch of warm current ≠ coastal stream of cold current
Near Shikotan Island, second branch of warm current ≠ Okhotsk current ≠ coastal stream of cold current

This may be because the fish are attracted by the abundant production of such natural foods of tuna as sardines and squid.

III. Observations Concerning Oceanographic Conditions

a. Pattern of Cold Currents in the Pacific Coast of Hokkaidō (Summer)

The following is an account of the Chishima cold current as observed by this Station within a radius of 200 miles from shore. The current runs south along the east coast of the Chishima chain to about 30 miles south of Noshappu where it is cut by water of the warm-current system into two branches. One branch runs from about 10 miles south of Kushiro

to about 10 miles off Erimosaki and then further divides into two branches, one of which goes to the Kinkazan area while the other runs from the Hitaka coast to Ezansaki and Shiriyasaki. This is tentatively called the coastal stream.

The latter passes 30 to 50 miles south of Kushiro, reaches a point about 40 miles south of Erimosaki, and then heads for the Kinkazan area. This is tentatively designated the second current, and it sometimes divides into two branches.

Number 3 moves south farther off shore than the second current, and flows down to the southwestward about 160 miles south of Kushiro. This is tentatively designated the third current. This is the pattern of the Chishima cold current.

b. Pattern of Warm Currents on the Pacific Coast of Hokkaido (Summer)

In May and June the Kuroshio warm current reaches the waters off Choshi and flows by in an approximately easterly direction. In July it is affected by the southerly seasonal winds and develops a branch which reaches into the waters off Kinkazan. In August this zone reaches to roughly the vicinity of 40° N where it is split by the third stream of the cold current, one branch turning eastward while the other continues north. The former is tentatively termed the first branch of the warm current. The northbound branch is bisected by the second stream of the cold current off Erimosaki, and one stream turns toward the off-shore waters about 100 miles south of Kushiro while the other approaches Erimosaki and turns toward the waters off Kushiro. The former is tentatively designated the second branch and the latter the third branch. The third branch mingles with the Tsugaru warm current.

The above, if one looks from the Kushiro shore, are arranged from the coast toward the open sea in the order of the coastal stream of the Chishima cold current, the third branch of the warm current, the second stream of the cold current, the second branch of the warm current, the third stream of the cold current, and the first branch of the warm current. This arrangement is shown in figure 3.

c. Characteristics of the Oceanographic Conditions During the Past 10 Years

1922.--A year of low temperatures in the off-shore waters. September was the season of highest temperatures. According to the regular observations it was a year of high temperatures on the coast in July, August, and September.

1923.--No transverse observations were taken and conditions off shore were not clear. According to the regular observations temperatures were low in July, August, and September, but they were high from October on.

1924.--Temperatures were low in July with the waters off Kushiro at 10.0°C or less, but from the latter part of the month they rose abruptly, and in the early part of August the third branch of the warm current showed 18.0°C to 21.0°C. In the latter part of August the second stream of the cold current strengthened and the temperatures went down to 15.0°C or below, but in the early part of September the water temperatures recovered.

1925.--Temperatures were 16.0°C or higher from July on and reached their highest in August. It was a year of high temperatures. At Kushiro the 20-mile station showed the lowest and the 30-mile station the highest readings.

1926.--The surface water temperatures were unusually low. August showed the maximum. In contrast to this, the middle and lower levels had high temperatures, that is, the vertical distribution of the warm current was thick. The range of the bottom layer of cold water, with temperatures of 2.0°C and lower, was small. At Kushiro the second stream of the Chishima cold current approached to the 20-mile station, and its range extended to the 40-mile station. The third branch of the warm current did not extend east of Kushiro. The water color was unfavorable and the transparency was notably low.

1927.--This was a year of high surface water temperatures, the maximum being reached in August, and the third branch of the warm current was vigorous. (In August the coastal stream of the cold current was not present on the line south of Kushiro.) The cold bottom water was strong, water of temperatures of 2.0°C or less having a wide range. Consequently the vertical distribution of the warm current was thin.

1928.--This was a year of high surface temperatures. The peak was in September and the period of falling temperatures was somewhat delayed. The range of the cold bottom water with temperatures of 2.0°C and lower was not great.

1929.--This was a year of low surface temperatures. The range of cold bottom water of 2.0°C and lower temperatures was extremely small. Accordingly the vertical distribution of the warm current was thick. The third branch of the warm current flourished off Erimosaki, but it was blocked off Kushiro by the cold current (the coastal stream and the second stream did not separate) and did not extend farther east.

1930.--The surface water temperatures were normal. The lower level was markedly cold and the range of water with temperatures of 2.0°C or less was large. Consequently the vertical distribution of the warm current was thin. On the Erimosaki line the difference in temperature between the surface and 40 meters was 11.7°C, the greatest in the past 6 years. The value on the Kushiro line was the fourth greatest in the past 8 years.

1931.--This was a year of rather low surface temperatures. Within 100 miles both currents had three branches apiece. Water temperatures at the 40 to 100-meter levels showed markedly low readings, meaning that the vertical distribution of the warm current was extremely thin.

1932.--This was a year of generally low water temperatures. The coastal stream of the cold current heading southward from Erimosaki was strong, and the third branch of the warm current did not pass north of the Erimo station line. The Erimo line had lower temperatures in August than in July. Water temperatures on the Erimo line were lower than those on the Kushiro line (July - November).

IV. Oceanographic Conditions and the Fishing Situation

a. Vertical Differential in Water Temperatures and Fishing Conditions

The results of observations made in August, 10 to 50 miles south of Kushiro, have been taken. In comparing the temperature differentials for the surface and levels from 10 to 200 meters, the yearly changes are greatest as between the surface and the 50-meter level, so this will be taken as representative. If the total landings are taken for the amount of the catch, the figure is likely to be affected by the number of boats engaged in the fishery, while if we take the average catch per boat it is likely to be controlled by the number of cruises made or by temporary changes in the number of boats putting in to the port, and in either case the figures will be lacking in accuracy. Therefore we have taken the average catch per cruise. Since in the case of the Kushiro boats one cruise is generally equivalent to one night, this is probably the most reasonable.

The result is that in years when the vertical differential in water temperature is small the fishing is good, and when the differential is great the fishing is poor.

The phenomenon of a small vertical temperature differential off Kushiro means either that the warm current is not strong, so that its force does not extend all the way to the Kuriles, or that the cold current is not strong, so that it does not reach to west of Kushiro, and thus the contact of the two currents is in the waters near Kushiro. In that case the center of the tuna schools is within the operating radius of the boats based at Kushiro and consequently they find good fishing. This theory is also confirmed by the fact that when the vertical differential in water temperatures at the Noshappusaki line and at the Erimosaki line is compared with the amount of the landings at Kushiro, the correlation is not close.

These facts are shown by table 9 and figure 4. The coefficient of correlation is $\underline{r} = -0.51$.

Table 9.--Fish catch and water temperature differential

Year	Catch	Boats operating	Average catch per boat	Total number of trips	Average trips per boat	Average catch per boat per trip	Surface temp. (10 to 50 mi. average)	50-meter temp. (10 to 50 mi. average)	Temperature Differential
	Pounds		Pounds			Pounds	°C	°C	°C
1923	1,223,853	43	28,465	1,233	29	992	--	--	--
1924	1,218,436	53	22,991	1,474	28	827	17.6	5.2	12.4
1925	2,743,200	43	63,795	1,882	44	1,456	17.1	6.2	10.9
1926	6,890,961	103	66,904	2,722	26	2,531	12.2	5.4	6.8
1927	8,601,759	272	31,625	5,361	20	1,604	18.0	2.6	15.4
1928	9,151,822	187	48,942	6,369	34	1,439	15.6	3.4	12.2
1929	24,792,236	258	96,097	10,804	42	2,299	14.6	6.8	7.8
1930	14,780,285	250	59,122	10,028	40	1,472	16.4	6.4	10.0
1931	14,867,806	266	55,897	11,404	43	1,307	15.7	5.4	10.3
1932	9,452,139	262	36,074	8,725	33	1,083	15.1	3.8	11.3

[Translator's note.--Catch weights have been converted at the rate of 8.27 pounds per kan.]

b. Position of Ocean Currents and Fishing Conditions

When the power of the second branch of the warm current is weak or the third branch of the warm current does not reach the waters off Noshappusaki, the coastal stream and the second stream of the Chishima cold current reach the waters off Kushiro without branching. (See section III.) August 1926 and September 1929 (no observations were made in August) are examples of this. The former extended from 20 miles south to 40 miles south of Kushiro, the latter from 10 to 40 miles south of Kushiro. The breadth of the current was great and the third branch of the warm current also failed to break through the line south of Kushiro. In such cases the fish which migrate east of Akkeshi are few, and the fishing is good at Kushiro, with many large tuna.

Off Erimosaki the third branch of the warm current (mingled with the Tsugaru warm current) ordinarily extends from the station 30 miles south of Erimosaki to the waters off Kushiro, but in 1932, because of the strength of the coastal stream of the cold current, the third branch of the warm current did not pass the line south of Erimosaki and consequently the migration of the tuna schools into the Kushiro area was blocked with the result that Urakawa had good fishing while the fishing was poor at Kushiro.

c. Strong Warm Currents and Fishing Conditions

When the third branch of the warm current is strong off Kushiro and the cold current is pushed back, there is sometimes rather good fishing. Examples of this situation are August 1925 and September 1928, and in both these years small tuna were remarkably numerous.

Considering the fishing situation for every year, in most cases the fishing is good in the latter part of July. This is because the tuna schools are in the area where the cold and warm currents are in contact, the schools are not scattered, and their position is clear.

d. Number of Sunspots and Fishing Conditions

Mr. Yōkichi Kurita[3] has investigated the relation between the number of sunspots and the tuna fishery of Mie Prefecture, and has reported that when the sunspots are at their minimum the fishing is good, while it is poor when they are at their maximum. The Assistant Technician of this Station has used the statistics of the Hokkaidō Government to compare the catch of tuna for all Hokkaidō with the number of sunspots and has reported that there is a positive correlation.[4] This means that the tuna catch in southern Japan and the catch in the North are opposite to each other. When the total catch at Kushiro and the number of sunspots are compared, they are positively correlated. However, taking into consideration the fact that the number of boats engaged in the tuna fishery has increased from year to year because of the recent rise of the fishery, and that

therefore the catch has increased even in poor years, a comparison with the average catch per boat per trip was made and failed to show any clear correlation, but it does appear that fishing is good around the time when the number of sunspots reaches its maximum and minimum.

e. Relations with Other Marine Animals

It is difficult to study the relations between the tuna and the other marine animals which are taken with it because there is little data on anything other than the broadbill swordfish. In years when many skipjack, albacore, broadbill, and marlin are mixed with the catch the fishing for tuna is poor, large tuna being particularly scarce. Skipjack were taken in large numbers by tuna gear in 1927 and 1928, and albacore were taken in 1927, 1928, and 1929, being most numerous in 1928. The rate of appearance of broadbill in the catch per 100 tuna was 0.8 in 1926, 6.6 in 1927, 3.8 in 1928, 1.2 in 1929, 3.1 in 1930, and 2.1 in 1931. When the broadbill were numerous, the tuna fishing was poor. This is shown graphically in figure 5. In 1922, 1923, 1925, and 1929, surumeika [Ommastrephes sloani pacificus Steenstrup] were abundant, but no relationship was evident.

f. Relation to Low Pressures and Wind Directions

The writer has already[5] plotted a curve of the tuna landings for each day at the Kushiro fish market. Designating the maximum catches (big hauls) as A, the minimum (poor catches) as a, rising air pressure as B, falling air pressure as b, and looking at their relations, we find that in 1926 they were Ab12, AB7, aB12, and ab4, while in 1927 they were Ab13, AB7, aB13, and ab6. In general it could be seen that the big catches were made when the atmospheric pressure fell, and when the pressure rose the fishing was poor.

This means that when there is a low in the Japan Sea and the direction of the winds blowing upon Hokkaido changes from northeast to south and the weather becomes bad, then the fishing is good for both long-line and drift-net fisheries. When the low passes and retreats to the Sea of Okhotsk or the Chishima area, the air pressure rises, and the westerly winds blow on the area, the catch decreases.

Furthermore[6] with regard to the correlation between the progress of lows and the tuna catch in the Kushiro region, taking as a starting point the day on which the center of a low approached its closest to Kushiro, when we thereafter look at the distribution of the number of fish caught in each 4-day period before and after that time, we find that the minimum catches are 3 days before and 1 day after and the maximum are 4 days and 1 day before and 4 days after the starting date.

g. Relation of Fish Catch to Lunar Age

Many of the Kushiro drift-net fishermen, believing that the fishing is poor before and after the full moon, rest from fishing and mend their nets during this period. Therefore the total catch is markedly small around the full moon. In order to determine whether or not the fishing was, after all, poor in the light of the moon and good on dark nights, the average number of fish taken per boat per trip for each day from 1929 to 1931 was calculated and the values were arranged in the order of lunar age as in figure 6. This shows that the catches are largest from the third to the eleventh day of the moon.

h. Conditions for Good Fishing Over a Long Period

As conditions for good fishing over a long period we have recorded the small vertical differential in water temperature, the great breadth of the coastal stream of the Chishima cold current in the waters off Kushiro, and the failure of the third branch of the warm current to break through it.

On the basis of the facts given above the writer wishes to propose the following hypothesis with regard to the tuna fishery:

In the case of a warm-water migratory fish like the tuna, the local fishing situation and the amount of the catch are controlled less by the total numbers of the fish present in the ocean than by the breadth or narrowness of the area of migration as influenced by the position of the ocean currents and their relative strength. Since this area is the limit of the distribution of the tuna, this hypothesis is most appropriate.

To judge from past facts, in years like 1926 and 1929, because the warm currents were not strong, the tuna schools did not go north into the Chishima area and their area of migration was restricted, giving rise to the phenomena of poor fishing at Etorofu and good fishing at Kushiro. In a year like 1932, when the cold water zone expanded greatly off Erimosaki, the third branch of the warm current was lacking, and the migration of small tuna into the Kushiro area was blocked, resulting in good fishing at Urakawa and poor fishing at Kushiro. In 1927, because of the great strength of the warm current, the tuna schools reached far into the Chishima area, and the area of migration was extended with the result that the tuna schools were scattered, and Kushiro had poor fishing, while the fishing was good at Etorofu.

The hypothesis presented above is confirmed by the inverse correlation between the tuna fisheries of southern Japanese waters and of the adjacent waters of Hokkaidō, and by the fact of an inverse correlation between the black-tuna catch and the broadbill-swordfish catch in Hokkaidō.

V. Summary

The items detailed above may be summarized as follows:

(1) The drift-net fishery for tuna in Hokkaidō began in 1905 with the incidental capture of tuna in drift nets set for shark, and at present has reached a flourishing condition at Kushiro and Urakawa. The establishment of the long-line fishery is comparatively recent, dating from 1926. The set-net fishery is oldest at Funkawan, and was started at Etorofu Island in 1917.

(2) The first catches in the drift-net fishery are made in the latter part of June (June 27 on the average) near Erimosaki. The main season is from the middle of July to the latter part of October, with the peak in August, and fishing ends in November (November 4 on the average, but much later in recent years). The grounds are in the waters east of Urakawa and lie comparatively close to the coast. The season in the long-line fishery is from August to December, and the grounds are in the waters west of Erimosaki. The set-net fishery in Funkawan is divided into two seasons.

The Etorofu Island set nets catch the largest fish, followed by those taken in the Funkawan set nets at the end of the season. The fish taken in the long-line fishery are larger than those taken in the drift-net fishery. In the Kushiro drift-net catch many large fish are taken at the beginning of the season, the average weight being 250 pounds or more, but gradually the number of medium and small tuna comes to exceed that of the large fish and the average weight comes to be 80 to 160 pounds. The number of large fish increases again somewhat at the end of the season.

(3) The following table shows a summary of the fishing situation and peculiar oceanographic phenomena during the past 11 years. /See next page./

(4) The paths of the tuna schools migrating to the Pacific coastal waters of Hokkaidō appear to follow these three routes: (A) those fish which are drawn by the warm Tsugaru current to Shiriyasaki and thence enter Funkawan, (B) those which move northward along the third branch of the warm current from off Erimosaki through the waters off Kushiro to the Etorofu Island area, and those which follow the Hitaka coastal waters from Erimosaki and enter Funkawan, and (C) those which reach the waters off Kushiro along the second branch of the warm current and then move on farther north. When they go south in the fall their routes are (A) along the coast from Erimosaki toward the Funkawan and Ezansaki areas, (B) from Erimosaki directly to the waters off Kamaishi, and (C) southward off shore with the retreat of the second branch of the warm current. The above may be called localized migrations in which the schools remain for a considerable length of time off Shiriyasaki, off Ezansaki, off Erimosaki, and off Kushiro.

Year	Oceanographic conditions	Fishing situation
1922	A year of low temperatures, details unknown.	Kushiro drift nets had poor fishing; situation at Etorofu I. and Funkawan unknown.
1923	According to the regular observations the summer was cold and the autumn had high temperatures; nothing else known.	Kushiro drift nets had poor fishing, mostly large tuna; poor fishing at Etorofu I.; situation at Funkawan unknown.
1924	July had low temperatures, rising sharply in August; there was a temporary sharp drop in water temperatures in the latter part of August.	Kushiro drift nets had poor fishing, mostly large tuna; Etorofu I. was rather good; nothing known of Funkawan.
1925	A year of high temperatures; the lowest was at a point 20 miles S of Kushiro, the highest at a point 30 miles S.	Kushiro drift nets had good fishing, small tuna rather plentiful; good fishing at Etorofu I.; nothing known of Funkawan.
1926	Lowest temperatures in 11 years; middle and lower levels had high temperatures; cold current broad; third branch of warm current did not reach to east of Kushiro.	Kushiro drift nets had good fishing, many large tuna; poor fishing at Etorofu I.; good fishing at Funkawan in November; good long-line fishing near Ezan.
1927	A year of high temperatures; the third branch of the warm current flourished; the bottom layer of cold water of 2.0°C and colder had a wide range.	Kushiro drift nets had poor fishing, fishing grounds were far-flung; Etorofu I. had the biggest catch in 9 years; good fishing at Funkawan in November; long-line fishing grounds extended from Shiriyasaki to Shikotan I., but fishing was poor.
1928	A year of high temperatures with the warm currents notably strong in September.	Kushiro drift nets had good fishing in September, many medium and small tuna; good fishing at Etorofu I.; good fishing at Funkawan in November; long-line fishing was good, fishing grounds extended to east of Erimosaki.

Year	Oceanographic conditions	Fishing situation
1929	A year of low temperatures; the cold lower-level water of 2.0°C or colder had a restricted range; the third branch of the warm current did not reach to east of Kushiro; the breadth of the cold current was great.	Kushiro drift nets had their best fishing in 11 years; the fishing grounds did not extend to east of Akkeshi, and were near the coast; large fish predominated; fishing was poor at Etorofu I. and Funkawan; long-line fishing was good west of Erimosaki.
1930	Water temperatures average; lower level had remarkably low temperature, water of 2.0°C and colder had a wide range.	Kushiro drift nets had moderately good fishing, mostly small tuna; poor fishing at Etorofu I.; good fishing for small tuna at Funkawan in August; long-line fishing extremely poor.
1931	Water temperatures average; there were three streams of the cold current within 100 miles of Kushiro; water temperatures at 40-100 meters were extremely low.	Kushiro drift nets had moderately good fishing, small tuna were very numerous; fishing was poor at Etorofu I.; fishing was good at Funkawan in October; long-line fishing was ordinary.
1932	Water temperatures were low; the third branch of the warm current did not pass the line of Erimosaki; temperatures along that line were lower in August than in July; the Erimo line had lower temperatures than the Kushiro line.	Kushiro drift nets had very poor fishing, medium tuna were taken in small numbers; good fishing at Urakawa, small tuna remarkably numerous; poor fishing at Etorofu I.; long-line fishing was poor.

(5) The first drift-net catches off Erimosaki are made at water temperatures of about 14°C. This figure is higher in warm years and lower in cold years. During the main season off Kushiro the water temperatures are 14.0°C to 18.0°C. At the close of the season there is good fishing even at temperatures of around 10.0°C. After visiting the coastal waters of Hokkaidō the fish are accustomed to cold water and their resistance to water temperature is great.

(6) The tuna like to live in zones of mixed water.

(7) In the Pacific coastal waters of Hokkaidō there are three streams of the Chishima cold current. The warm currents are three streams of water from the Kuroshio system and the Tsugaru warm current.

(8) The temperature differential between the surface and the 50-meter level in transverse observations 10 to 50 miles south of Kushiro and the average catch per boat per cruise are inversely correlated, with a correlation coefficient of $\underline{r} = -0.51$.

(9) The position and strength of the ocean currents control the tuna fishery. When the coastal stream of the Chishima cold current and its second stream do not separate, or the third branch of the warm current does not break through the cold current off Kushiro, the fishing is good at Kushiro and poor at Etorofu Island. When the third branch of the warm current does not flow off Erimosaki, the fishing is poor at Kushiro and good at Urakawa.

(10) The fishing is sometimes good when the warm currents are flourishing, and in most years the fishing is good in the latter part of July.

(11) The tuna-fishing situation in the southern waters of Japan and that of the Hokkaidō waters appear to be directly opposite. There also seems to be some correlation with the number of sunspots, but this is hard to affirm because of the paucity of data.

(12) Fishing is poor in years when broadbill swordfish, skipjack, albacore, and other warm-water fish migrate into the area.

(13) Generally when a low is approaching and the wind direction becomes easterly the fishing is good.

(14) There is a correlation between lunar age and the drift-net fishery. In general the fishing is good from the third to the eleventh day of the lunar month.

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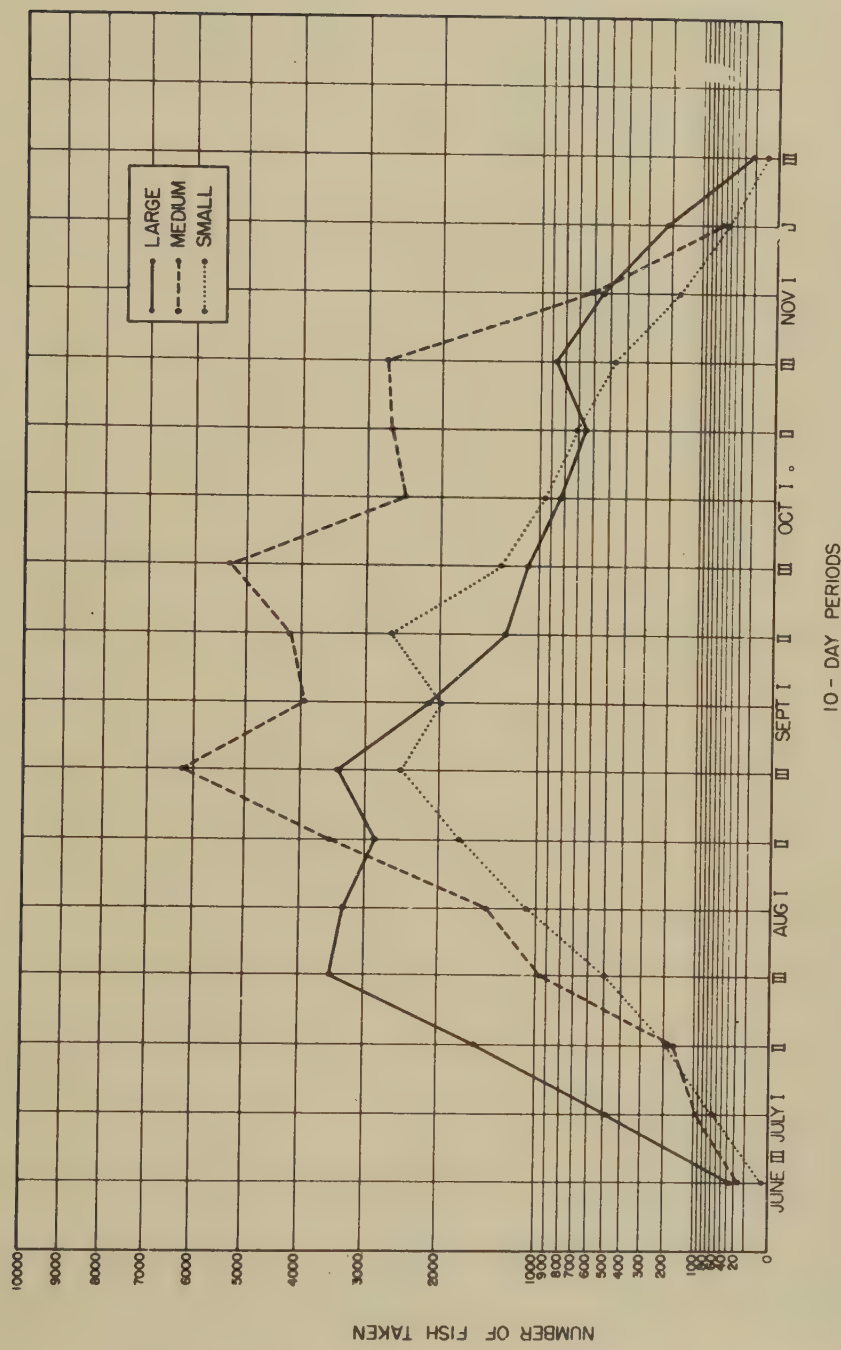

Figure 1. Catch by sizes and 10-day periods (average for 10 years, 1922-31).

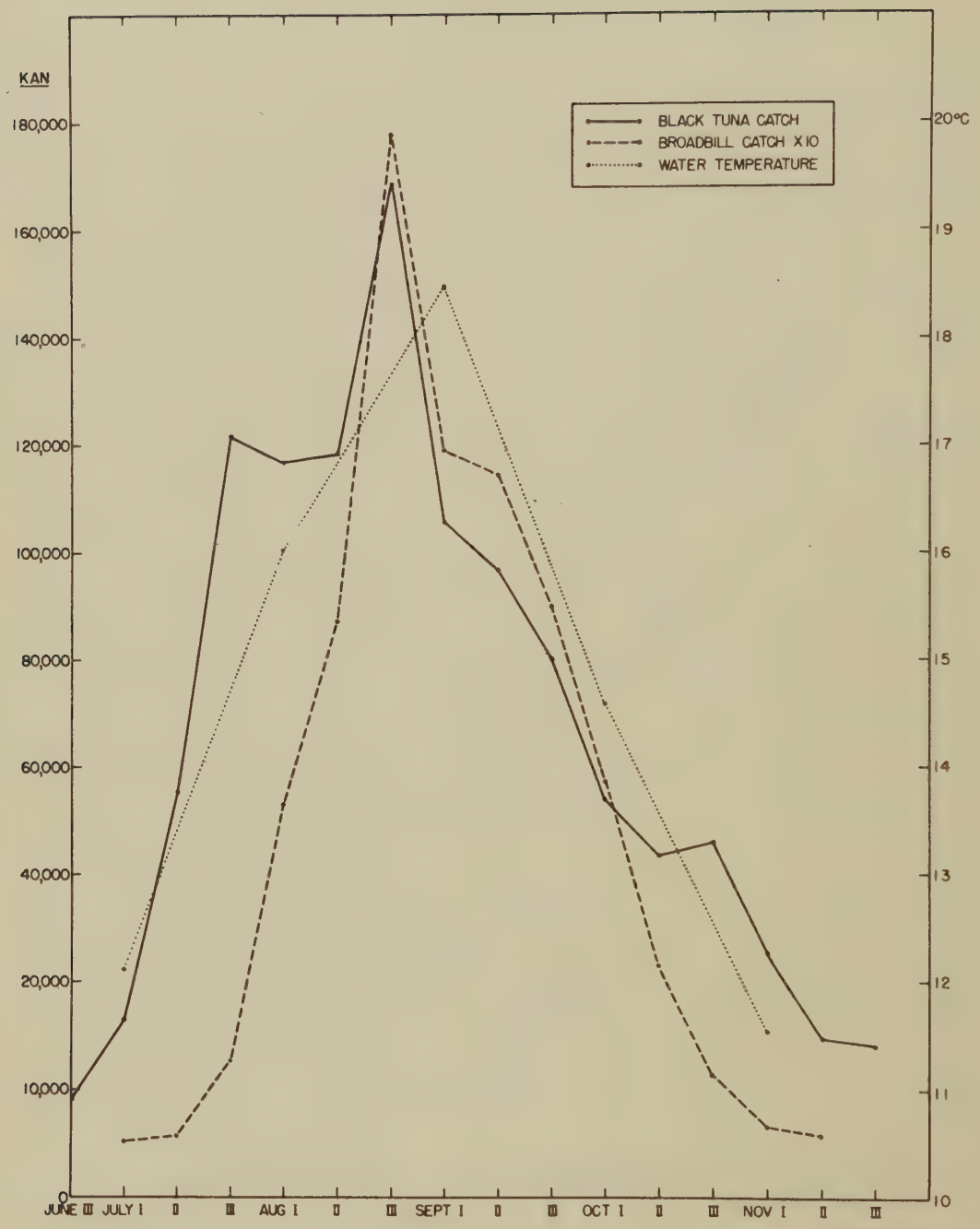

Figure 2. Ten-year averages (1922-31) of black-tuna and broadbill catches (by 10-day periods) and surface water temperature (10 to 50 miles).

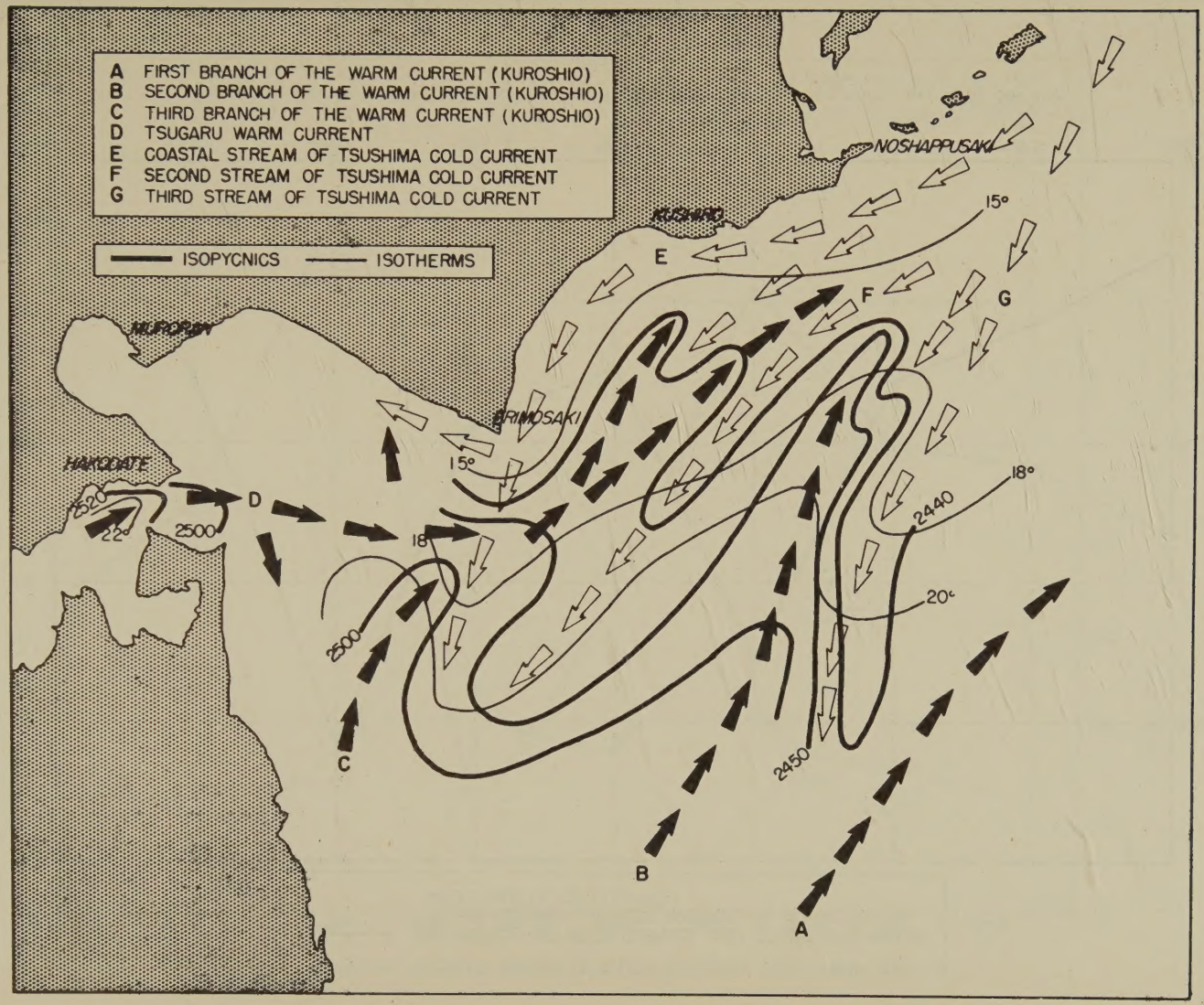

Figure 3. Chart of the current systems on the Pacific Coast (August).

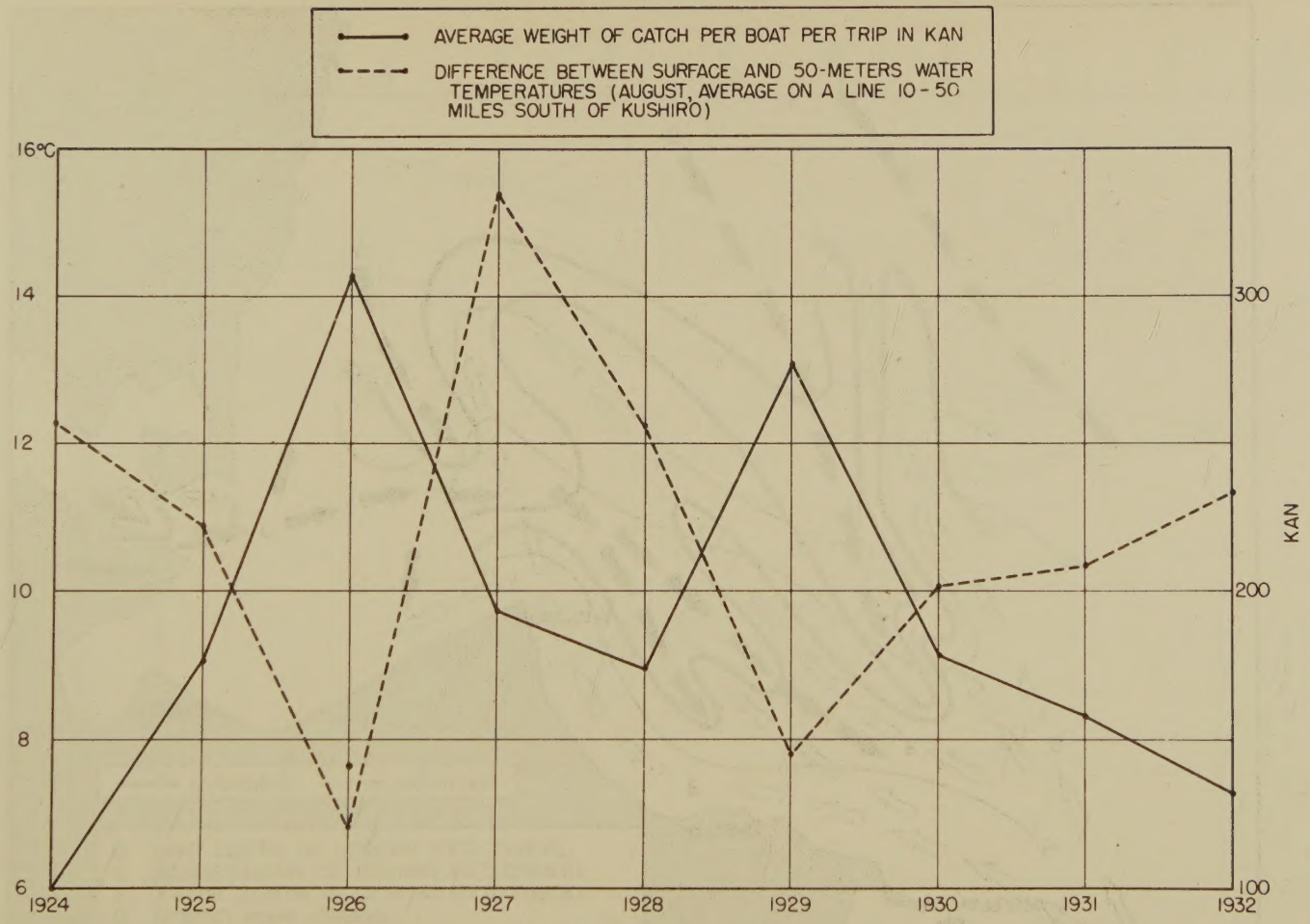

Figure 4. Relation of water temperature differential to the average catch per boat per trip.

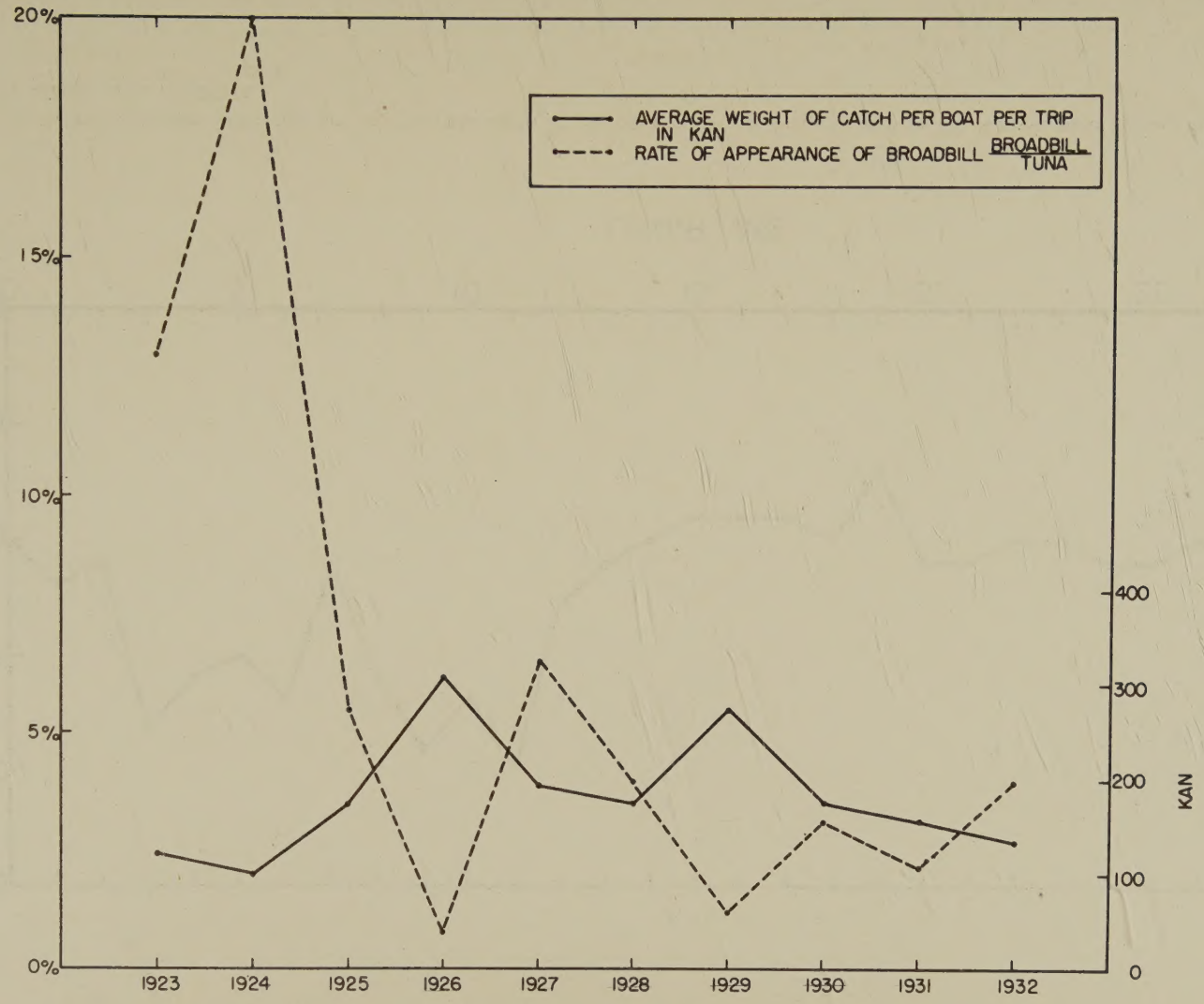

Figure 5. Relation between catch and rate of appearance of broadbill swordfish.

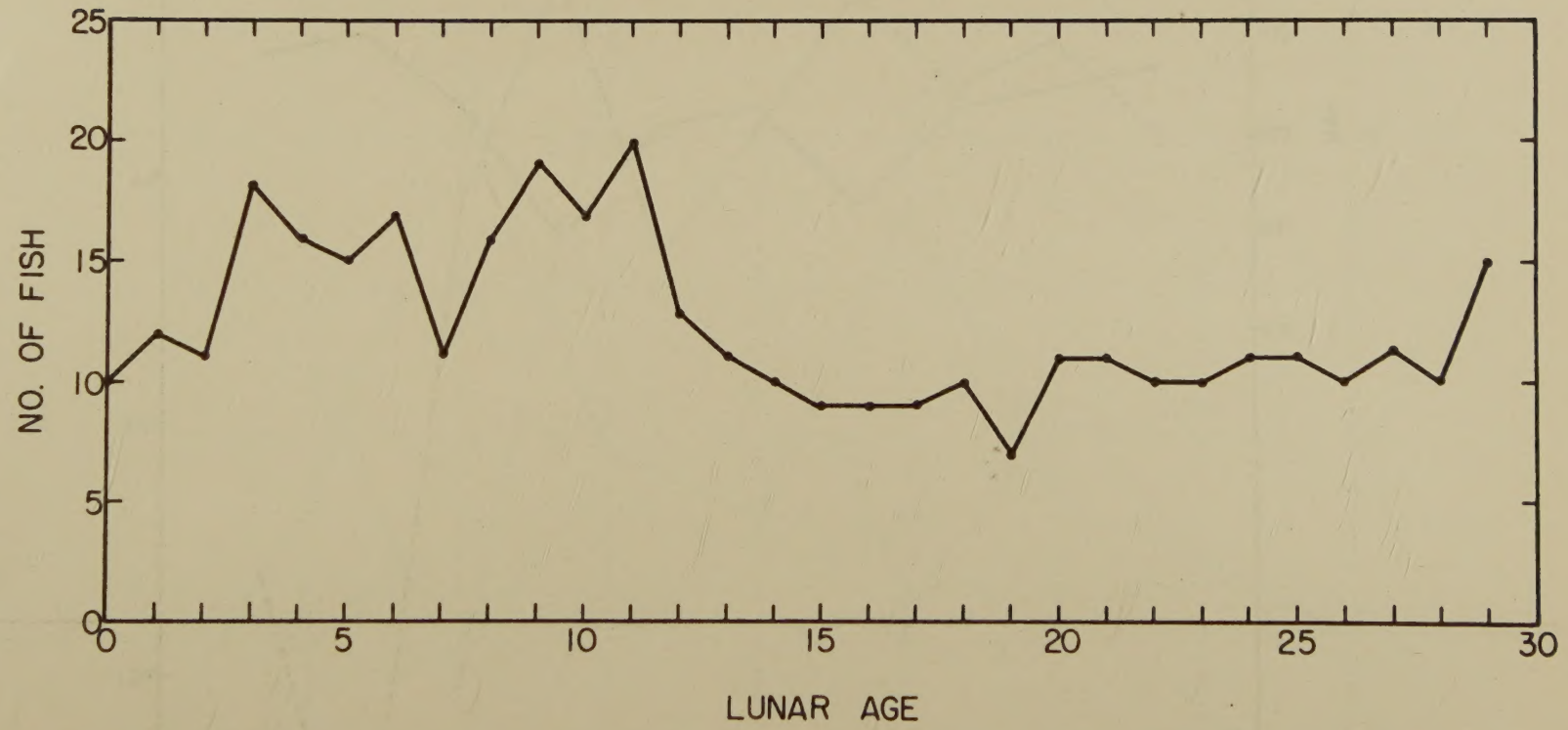

Figure 6. Relation between lunar age and the average catch in number of fish per boat per trip in the Kushiro tuna fishery (average for 3 year period from 1929-31).